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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of:	)	Group Art Unit: 2874
Koichiro TANAKA et al.	)	Examiner: M. Stahl
Serial No. 10/827,449	)	CERTIFICATE OF MAILING I hereby certify that this correspondence is being deposited with the United States Postal Service with sufficient postage as First Class Mail in an envelope addressed to: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450, on November 13, 2007.
Filed: April 20, 2004	)	
For: BEAM HOMOGENIZER, LASER IRRADIATION APPARATUS, AND METHOD FOR MANUFACTURING SEMICONDUCTOR DEVICE	)	Adele M Stamper

SUBMISSION OF VERIFIED ENGLISH TRANSLATIONS

Honorable Commissioner of Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

Further to the *Amendment* filed on August 15, 2007, in order to overcome the rejections based on JP 2003-287703 or CN 1448753, verified English translations of priority applications JP 2003-120782 and JP 2003-342803, each filed April 24, 2003, are submitted herewith. Since JP '703 was published October 10, 2003, and since CN '753 was published October 15, 2003, which is later than the filing date of JP '782 and JP '803, the Applicant respectfully submits that the rejections under §§ 102(a) and 103 should be overcome. Accordingly, reconsideration and withdrawal of the rejections under 35 U.S.C. §§ 102(a) and 103 are in order and respectfully requested.

Should the Examiner believe that anything further would be desirable to place this application in better condition for allowance, the Examiner is invited to contact the undersigned at the telephone number listed below.

Respectfully submitted,

Eric J. Robinson
Reg. No. 38,285

Robinson Intellectual Property Law Office, P.C.
PMB 955
21010 Southbank Street
Potomac Falls, Virginia 20165
(571) 434-6789

Docket No.: 0756-7293

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In re Patent Application of:	)
Koichiro TANAKA et al.	)
Application No.: 10/827449	) Examiner: M. Stahl
Filed: April 20, 2004	) Group Art Unit: 2874
For: BEAM HOMOGENIZER, LASER	)
IRRADIATION APPARATUS, AND	)
METHOD FOR MANUFACTURING	)
SEMICONDUCTOR DEVICE	)

VERIFICATION OF TRANSLATION

Commissioner for Patents
P.O.Box 1450
Alexandria, VA 22313-1450

Sir:

I, Akiko NORIO, C/O Semiconductor Energy Laboratory Co., Ltd. 398, Hase, Atsugi-shi, Kanagawa-ken 243-0036 Japan, a translator, herewith declare:

that I am well acquainted with both the Japanese and English Languages;

that I am the translator of the attached translation of the Japanese Patent Application No. 2003-120782 filed on April 24, 2003; and

that to the best of my knowledge and belief the following is a true and correct translation of the Japanese Patent Application No. 2003-120782 filed on April 24, 2003.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Date: this 5th day of November 2007

Akiko Norio

Name: Akiko NORIO

[Name of Document] Patent Application

[Reference Number] P007113

[Filing Date] April 24, 2003

[Attention] Commissioner, Patent Office, Shinichiro OTA

[Inventor]

[Address] 398 Hase, Atsugi-shi, Kanagawa-ken
c/o Semiconductor Energy Laboratory Co., Ltd.

[Name] Koichiro TANAKA

[Inventor]

[Address] 398 Hase, Atsugi-shi, Kanagawa-ken
c/o Semiconductor Energy Laboratory Co., Ltd.

[Name] Tomoaki MORIWAKA

[Applicant]

[Identification Number] 000153878

[Name] Semiconductor Energy Laboratory Co., Ltd.

[Representative] Shunpei YAMAZAKI

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[List of Attachment]

[Attachment] Specification 1

[Attachment] Drawing 1

[Attachment] Abstract 1

[Proof] Required

[Document Name] Specification

[Title of the Invention]

BEAM HOMOGENIZER, LASER IRRADIATION APPARATUS, AND METHOD FOR MANUFACTURING SEMICONDUCTOR DEVICE

[Scope of Claims]

[Claim 1]

A beam homogenizer for shaping a beam spot into a rectangular beam spot having an aspect ratio of 10 or more on a surface to be irradiated, characterized by comprising:

an optical waveguide for homogenizing energy distribution of the rectangular beam spot in a direction of its major axis.

[Claim 2]

A beam homogenizer for shaping a beam spot into a rectangular beam spot having an aspect ratio of 10 or more on a surface to be irradiated, characterized by comprising:

an optical waveguide for homogenizing energy distribution of the rectangular beam spot in a direction of its major axis;

one cylindrical lens or a plurality of cylindrical lenses for expanding a plane having homogeneous energy distribution, which is formed by the optical waveguide, in a direction of the major axis of the rectangular beam spot and projecting the plane on the surface to be irradiated.

[Claim 3]

A beam homogenizer for shaping a beam spot into a rectangular beam spot having an aspect ratio of 10 or more on a surface to be irradiated, characterized by

comprising:

a means for homogenizing energy distribution of the rectangular beam spot in the direction of its minor axis on the surface to be irradiated; and

an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in a direction of its major axis,

wherein the means has at least a cylindrical lens array.

[Claim 4]

A beam homogenizer for shaping a beam spot into a rectangular beam spot having an aspect ratio of 10 or more on a surface to be irradiated, characterized by comprising:

an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in a direction of its major axis; and

an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in a direction of its minor axis.

[Claim 5]

A beam homogenizer according to any one of claims 1 to 4, characterized in that the optical waveguide has a pair of reflection planes provided oppositely.

[Claim 6]

A beam homogenizer according to any one of claims 1 to 5 according to any one of claims 1 to 4, characterized in that the optical waveguide is a light pipe.

[Claim 7]

A beam homogenizer according to any one of claims 1 to 6, characterized in that the aspect ratio is 100 or more.

[Claim 8]

A laser irradiation apparatus having an aspect ratio of 10 or more on a rectangular beam spot on a surface to be irradiated, characterized by comprising;

a laser oscillator; and

a beam homogenizer,

wherein the beam homogenizer comprises an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in a direction of its major axis.

[Claim 9]

A laser irradiation apparatus having an aspect ratio of 10 or more on a rectangular beam spot on a surface to be irradiated, characterized by comprising;

a laser oscillator; and

a beam homogenizer,

wherein the beam homogenizer comprises an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in a direction of its major axis, and a means for homogenizing energy distribution of the rectangular beam spot in the direction of its minor axis; and

wherein the means has at least a cylindrical lens array.

[Claim 10]

A laser irradiation apparatus having an aspect ratio of 10 or more on a rectangular beam spot on a surface to be irradiated, characterized by comprising;

a laser oscillator; and

a beam homogenizer,

wherein the beam homogenizer comprises an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in a direction of its

major axis; and the optical waveguide for homogenizing energy distribution of the rectangular beam spot in the direction of its minor axis.

[Claim 11]

A laser irradiation apparatus according to any one of claims 8 to 10, characterized in that the optical waveguide has a pair of reflection planes provided oppositely.

[Claim 12]

A laser irradiation apparatus according to any one of claims 8 to 11, characterized in that the optical waveguide is a light pipe.

[Claim 13]

A laser irradiation apparatus according to any one of claims 8 to 12, characterized in that the laser oscillator is an excimer laser, a YAG laser, or a glass laser.

[Claim 14]

A laser irradiation apparatus according to any one of claims 8 to 12, characterized in that the laser oscillator is a YVO_4 laser, a YLF laser, or an Ar laser.

[Claim 15]

A laser irradiation apparatus according to any one of claims 8 to 14, characterized in that the aspect ratio is 100 or more.

[Claim 16]

A laser irradiation apparatus according to any one of claims 8 to 15, characterized by comprising a moving stage for moving an object to be irradiated having the surface to be irradiated relatively to the beam spot.

[Claim 17]

A laser irradiation apparatus according to claim 16, characterized in that the

laser irradiation apparatus has a transferring apparatus for transferring the object to be irradiated having the surface to be irradiated to the moving stage.

[Claim 18]

A method for manufacturing a semiconductor device, characterized by comprising the steps of:

forming a non-single crystalline semiconductor film over a substrate; and

performing laser annealing to the non-single crystalline semiconductor film with a laser beam generated in a laser oscillator and shaped into a rectangular beam spot having an aspect ratio of 10 or more on a surface to be irradiated and homogeneous energy distribution through a cylindrical lens array and an optical waveguide, while moving a position of the beam spot relatively to the non-single crystalline semiconductor film assuming that the non-single crystalline semiconductor film is the surface to be irradiated,

wherein the cylindrical lens array acts upon the rectangular beam spot in a direction of its minor axis, and

wherein the optical waveguide acts upon the rectangular beam spot in a direction of its major axis.

[Claim 19]

A method for manufacturing a semiconductor device, characterized by comprising the steps of:

forming a non-single crystalline semiconductor film over a substrate; and

performing laser annealing to the non-single crystalline semiconductor film with a laser beam generated in a laser oscillator and shaped into a rectangular beam spot having an aspect ratio of 10 or more on a surface to be irradiated and homogeneous

energy distribution through a plurality of optical waveguides, while moving a position of the beam spot relatively to the non-single crystalline semiconductor film assuming that the non-single crystalline semiconductor film is the surface to be irradiated,

wherein at least one of the plurality of optical waveguides acts upon the rectangular beam spot in a direction of its major axis, and

wherein at least one of the plurality of optical waveguides acts upon the rectangular beam spot in a direction of its minor axis.

[Claim 20]

A method for manufacturing a semiconductor device, according to any one of claims 18 to 19, characterized in that the optical waveguide has a pair of reflection planes provided oppositely.

[Claim 21]

A method for manufacturing a semiconductor device, according to any one of claims 18 to 20, characterized in that the optical waveguide is a light pipe.

[Claim 22]

A method for manufacturing a semiconductor device, according to any one of claims 18 to 21, characterized in that the laser oscillator is an excimer laser, a YAG laser, or a glass laser.

[Claim 23]

A method for manufacturing a semiconductor device, according to any one of claims 18 to 21, characterized in that the laser oscillator is a YVO_4 laser, a YLF laser, or an Ar laser.

[Claim 24]

A method for manufacturing a semiconductor device, according to any one of

claims 18 to 23, characterized in that the aspect ratio is 100 or more.

[Detailed Description of the Invention]

[0001]

[Technical Field to which the Invention pertains]

The present invention relates to a beam homogenizer for homogenizing a beam spot on a surface to be irradiated in a certain region. The present invention also relates to a laser irradiation apparatus for irradiating the surface to be irradiated with the beam spot. Furthermore, the present invention also relates to a semiconductor device using a crystalline semiconductor film formed with the laser irradiation apparatus.

[0002]

[Conventional Art]

In recent years, there has been a technique widely studied for crystallizing or enhancing a crystallinity of an amorphous semiconductor film or a crystalline semiconductor film (a semiconductor film having a crystallinity such as poly crystal or micro crystal, which is not single crystal), that is to say, a semiconductor film which is not single crystal (referred to as a non single crystalline semiconductor film) formed over an insulating substrate of glass or the like with laser annealing performed thereto. A silicon film is often used as the semiconductor film.

[0003]

In comparison with a quartz substrate that has been used conventionally, a glass substrate has advantages that it is inexpensive and superior in workability, and that it can be processed easily into a large sized substrate. This is the reason why the study has been extensively conducted. A laser is preferably used for crystallization because the glass substrate has a low melting point. A laser can give high energy only to the

non-single crystalline semiconductor film without changing the temperature of the substrate too much.

[0004]

A crystalline silicon film formed with the laser annealing performed has a high mobility. Therefore, a thin film transistor (TFT) formed with this crystalline silicon film is used extensively. For example, the crystalline silicon film is extensively used in a monolithic liquid crystal electro-optical device and the like in which a TFT for a pixel and a TFT for a driver circuit are formed on one glass substrate. The crystalline silicon film is referred to as a poly crystalline silicon film or a poly crystalline semiconductor film because the crystalline silicon film is formed of a number of crystal grains.

[0005]

In addition, it is possible to shape a laser beam of high output pulsed oscillation, such as an excimer laser, into a square spot with several cm on a side or into a linear spot with 10 cm or more in length on the surface to be irradiated by an optical system (for example, Patent Document 1). Then the beam spot is scanned relatively to the surface to be irradiated to perform the laser annealing. Since such a method can enhance productivity and is superior industrially, it is preferably employed.

[0006]

In particular, when the linear beam spot is employed, unlike a punctate beam spot required to be scanned from front to back and from side to side, the linear beam spot can provide high productivity since the surface to be irradiated can be entirely irradiated by scanning the linear beam spot only in a direction perpendicular to the direction of its major axis. Here, the linear beam spot means a rectangular beam spot having a high aspect ratio. The beam spot is scanned in the direction perpendicular to

the direction of the major axis of the linear beam spot because it is the most effective scanning direction. Because of such high productivity, at present, the laser annealing is mainly employing the linear beam spot obtained by shaping a beam spot of a pulsed excimer laser through an appropriate optical system.

[0007]

FIGS. 6 show an example of the optical system for processing a cross-sectional shape of a beam spot into a linear shape on the surface to be irradiated. The optical system shown in FIGS. 6 is an extremely general optical system. The optical system not only converts the cross-sectional shape of the beam spot into the linear shape but also homogenizes the energy of the beam spot on the surface to be irradiated simultaneously. Generally, the optical system for homogenizing the energy of the beam is referred to as a beam homogenizer. The optical system shown in FIGS. 6 is also a beam homogenizer.

[0008]

First, a side view of FIG. 6 (a) is explained. A beam spot of a laser beam oscillated from a laser oscillator 1201 is divided in one direction through cylindrical lens arrays 1202a and 1202b. The direction is referred to as a vertical direction. When a mirror is inserted in the optical system, a beam spot in the vertical direction is bent in the direction of light bent by the mirror. The laser beam is divided into four beams in this structure. These divided spots are combined into one spot with a cylindrical lens 1204 once. After the spots separated again are reflected on a mirror 1207, the beam spots are converged into one spot again with a doublet cylindrical lens 1208 on a surface to be irradiated 1209. A doublet cylindrical lens is a set of lenses consisting of two cylindrical lenses. This homogenizes the energy of the beam spot

shaped to have the linear shape in the vertical direction and determines the length thereof in the vertical direction.

[0009]

Next, a plane view of FIG. 6 (b) is explained. The beam spot of a laser beam oscillated from the laser oscillator 1201 is divided in a direction perpendicular to the vertical direction through a cylindrical lens array 1203. The direction perpendicular to the vertical direction is referred to as a horizontal direction. When a mirror is inserted in the optical system, a beam spot in the horizontal direction is bent to the direction of light bent by the mirror. The laser beam is divided into seven beam spots in this structure. After that, the beam spots divided into seven beam spots are combined into one beam spot on the surface to be irradiated 1209 with a cylindrical lens 1205. A dotted line shows a correct optical path and correct positions of the lens and surface to be irradiated in the case where the mirror 1207 is not disposed. This homogenizes the energy distribution of the beam spot shaped to have the linear shape in the horizontal direction and determines the length thereof in the horizontal direction.

[0010]

As described above, the cylindrical lens arrays 1202a, 1202b, and 1203 are the lenses for dividing the beam spot of the laser beam. The number of the divided beam spots determines the homogeneity of the energy distribution of the obtained linear beam spot.

[0011]

Each of the lenses described above is made of synthetic quartz in order to correspond with the XeCl excimer laser. In addition, the lenses have coated surfaces thereon so that the excimer laser transmits through the lenses very much. This makes

transmittance of the excimer laser be 99% or more per one lens.

[0012]

The linear beam spot shaped with the above structure is delivered as being overlapped in such a way that the linear beam spot is displaced gradually in the direction of the line width of the beam spot. With such irradiation performance, the laser annealing can be conducted to the whole surface of the non-single crystalline silicon film, for example, so as to crystallize it or to enhance its crystallinity.

[0013]

Next, a typical method for manufacturing a semiconductor film, which becomes an object to be irradiated by the laser beam, is shown. Initially, a glass substrate having a thickness of 0.7 mm and a length of 5 inch on a side is used. A SiO_2 film (a silicon oxide film) is formed over the substrate in about 200 nm thick with a plasma-CVD apparatus, and an amorphous silicon film (hereinafter referred to as an a-Si film) is formed in about 50 nm thick over a surface of the SiO_2 film. When the substrate is exposed to the atmosphere of nitrogen at a temperature of 500°C for one hour, hydrogen concentration in the film is decreased. Accordingly, the resistivity of the film is considerably increased against the laser beam.

[0014]

A XeCl excimer laser (wavelength 308 nm, pulse width 30 ns) is used as the laser oscillator. A spot size of the laser beam is 15 mm × 35 mm at an exit of the laser beam (both are width at half maximum). The exit of laser beam is defined as a plane perpendicular to the traveling direction of the laser beam just after the laser beam is emitted from the laser oscillator.

[0015]

The laser beam emitted from the excimer laser usually has a rectangular shape, and when it is expressed with an aspect ratio, the rectangular beam has an aspect ratio ranging from approximately 1 to 5. The laser beam spot has Gaussian energy distribution in which the intensity of the laser beam spot becomes higher toward the center thereof. The spot size of the laser beam is changed into a spot shape having homogeneous energy distribution, for example, a linear beam spot having a size of 300 mm × 0.4 mm through the optical system shown in FIGS. 6.

[0016]

When the semiconductor film is irradiated with, the laser beam about 1/10 of the minor width (width at half maximum) of the linear beam spot is the most appropriate pitch for overlapping the laser beam spot. Accordingly, the homogeneity of the crystallinity in the semiconductor film can be improved. In the above example, since the width at half maximum is 0.4 mm, the laser beam is delivered under the condition of the excimer laser of which the pulse frequency is 300 Hz and the scanning speed is 10 mm/s. On this occasion, the energy density of the laser beam on the surface to be irradiated is set to 450 mJ/cm^2. The method described above is a very general method for crystallizing the semiconductor film with the linear laser beam spot.

[0017]

[Patent Document 1]

Japanese Patent Publication No. 9-234579

[0018]

[Problems to be Solved by the Invention]

The above cylindrical lens array requires to be manufactured with high accuracy.

[0019]

The cylindrical lens array is a lens with cylindrical lenses arranged in a direction of its curvature. Here, the direction of the curvature is defined as a direction perpendicular to a generating line of a cylindrical surface of the cylindrical lens. The cylindrical lens array always has a joint between the cylindrical lenses constituting the cylindrical lens array. Since the joint does not have a curved surface of the cylindrical lens, a light beam being incident into the joint is transmitted without being influenced by the cylindrical lens. The light beam reaching the surface to be irradiated without being influenced by the cylindrical lens may cause inhomogeneity of the energy distribution of the rectangular beam spot on the surface to be irradiated.

[0020]

In addition, all the cylindrical lenses constituting the cylindrical lens array must be manufactured with the same accuracy. When the cylindrical lenses have different curvatures, the light beams divided by the cylindrical lens array are not overlapped on the same position in the surface to be irradiated even with a converging lens. In other words, the region where the energy is attenuated in the rectangular beam spot on the surface to be irradiated increases. This causes the lowering of the energy usability.

[0021]

The cause of the inhomogeneous energy distribution of the beam spot on the surface to be irradiated lies in the structural problem and the manufacturing accuracy of the cylindrical lens array constituting the optical system. More specifically, one of the reasons of the inhomogeneity is that all the light beams divided by the cylindrical lens array are not overlapped on the same position.

[0022]

Furthermore, when the semiconductor film is irradiated and scanned with the rectangular beam spot having inhomogeneous energy distribution in the direction of its major axis on the surface to be irradiated, the crystallinity of the semiconductor film becomes inhomogeneous in a reflection of the inhomogeneous distribution. The inhomogeneity of the crystallinity is synchronized with the inhomogeneity of the characteristic of the semiconductor film such as the electrical mobility. For example, the inhomogeneous crystallinity appears as a variation of an electric characteristic of the TFT formed using the semiconductor film, and displays light and shade pattern on a panel using the TFT.

[0023]

The present invention is made in view of the above problem. The present invention provides a beam homogenizer capable of forming a rectangular beam spot having homogeneous energy distribution in the direction of its major axis on the surface to be irradiated without using the optical lens that is necessary to be manufactured with high accuracy. In addition, the present invention provides a laser irradiation apparatus capable of delivering a laser beam having a rectangular beam spot with homogeneous energy distribution in the direction of its major axis. Furthermore, the present invention provides a method for manufacturing a semiconductor device, capable of enhancing the homogeneity of the crystallinity in the surface of the substrate and of manufacturing a TFT with an excellent operating characteristic.

[0024]

[Means for Solving the Problem]

The present invention employs an optical waveguide as the optical system for homogenizing the energy distribution of the rectangular beam spot in the direction of its

major axis on the surface to be irradiated in the optical system for forming the above rectangular beam spot. The optical waveguide is a circuit capable of keeping radiation light in a certain region and transmitting the radiation light in such a way that the energy flow thereof is guided in parallel with an axis of the channel.

[0025]

This specification discloses a beam homogenizer for shaping a beam spot into a rectangular beam spot having an aspect ratio of 10 or more, preferably 100 or more, on a surface to be irradiated, comprising an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in the direction of its major axis.

[0026]

In the present invention, the reason why the optical waveguide is used in the beam homogenizer is explained as follows. When the light beams are incident into the optical waveguide, the light beams are reflected in the optical waveguide repeatedly and are led to the exit surface. In other words, the light beams being incident into the optical waveguide are overlapped as if the incident light beams are folded on the exit surface, which is the same position. Therefore, the energy distribution of the light beams is homogenized in the exit surface, on which the light beams are overlapped, since the light beams being incident into the optical waveguide are divided and obtain an effect similar to that in a case where the divided light beams are overlapped on the same position.

[0027]

Another structure of the present invention is a beam homogenizer for shaping a beam spot into a rectangular beam spot having an aspect ratio of 10 or more, preferably 100 or more, on a surface to be irradiated. The beam homogenizer comprises an

optical waveguide for homogenizing the energy distribution of the rectangular beam spot in a direction of its major axis, and one cylindrical lens or a plurality of cylindrical lenses for converging the light emitted from the optical waveguide in the direction of its major axis on the surface to be irradiated.

[0028]

Another structure of the present invention is a beam homogenizer for shaping a beam spot into a rectangular beam spot having an aspect ratio of 10 or more, preferably 100 or more, on a surface to be irradiated. The beam homogenizer comprises means for homogenizing energy distribution of the rectangular beam spot in the direction of its minor axis on the surface to be irradiated, and an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in a direction of its major axis, in which the means has at least a cylindrical lens array.

[0029]

Another structure of the present invention is a beam homogenizer for shaping a beam spot into a rectangular beam spot having an aspect ratio of 10 or more, preferably 100 or more, on a surface to be irradiated. The beam homogenizer comprises an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in a direction of its major axis, and an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in a direction of its minor axis.

[0030]

In the above structure of the beam homogenizer in the present invention, the optical waveguide has a feature to include a pair of reflection planes provided oppositely.

[0031]

In addition, a light pipe can be used as the optical waveguide. The light pipe is generally formed to have a cone shape, pyramidal shape, a columnar shape, a prismatic shape, or the like, which transmits the light from one end to the other end by reflection. In addition, the light may be transmitted by mirror reflection, and a pair of reflection planes provided oppositely may be employed, for example.

[0032]

This specification discloses a laser irradiation apparatus having an aspect ratio of 10 or more, preferably 100 or more, on a rectangular beam spot on a surface to be irradiated. The laser irradiation apparatus comprises a feature to include a laser oscillator and a beam homogenizer, in which the beam homogenizer comprises an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in a direction of its major axis.

[0033]

Another structure of the present invention is a laser irradiation apparatus having an aspect ratio of 10 or more, preferably 100 or more, on a rectangular beam spot on a surface to be irradiated. The laser irradiation apparatus comprises a feature to include a laser oscillator and a beam homogenizer, in which the beam homogenizer comprises an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in a direction of its major axis and an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in a direction of its minor axis.

[0034]

In the above structure of the laser irradiation apparatus in the present invention, the optical waveguide has a pair of reflection planes provided oppositely.

[0035]

In addition, a light pipe can be used as the above optical waveguide.

[0036]

In the above structure of the laser irradiation apparatus in the present invention, the laser oscillator is selected from an excimer laser, a YAG laser, a glass laser, a YVO_4 laser, a YLF laser, and an Ar laser.

[0037]

In the above structure of the laser irradiation apparatus in the present invention, the laser irradiation apparatus has a feature to comprise a moving stage for moving an object to be irradiated relatively to the beam spot and further comprises a transferring apparatus for transferring the object to be irradiated to the stage.

[0038]

The present invention discloses a method for manufacturing a semiconductor device comprising the steps of forming a non-single crystalline semiconductor film over a substrate, and performing laser annealing to the non-single crystalline semiconductor film with a laser beam while moving a position of a beam spot relatively to the non-single crystalline semiconductor film, assuming that the non-single crystalline semiconductor film is the surface to be irradiated. The laser beam is generated in a laser oscillator and then shaped into a rectangular beam spot having an aspect ratio of 10 or more, preferably 100 or more, and having homogeneous energy distribution through a cylindrical lens array and an optical waveguide. The cylindrical lens array acts upon the rectangular beam spot in a direction of its minor axis, and the optical waveguide acts upon the rectangular beam spot in a direction of its major axis.

[0039]

Another structure of the present invention is a method for manufacturing a semiconductor device comprising the steps of forming a non-single crystalline semiconductor film over a substrate, and performing laser annealing to the non-single crystalline semiconductor film with a laser beam while moving a position of a beam spot relatively to the non-single crystalline semiconductor film, assuming that the non-single crystalline semiconductor film is the surface to be irradiated. The laser beam is generated in a laser oscillator and then shaped into a rectangular beam spot having an aspect ratio of 10 or more, preferably 100 or more, and having homogeneous energy distribution through a plurality of optical waveguides. At least one of the plurality of optical waveguides acts upon the rectangular beam spot in a direction of its major axis, and at least one of the plurality of optical waveguides acts upon the rectangular beam spot in a direction of its minor axis.

[0040]

In addition, a light pipe can be used as the optical waveguide.

[0041]

In the above structure of the method for manufacturing a semiconductor device in the present invention, the laser oscillator is selected from an excimer laser, a YAG laser, a glass laser, a YVO_4 laser, a YLF laser, and an Ar laser.

[0042]

[Embodiment Mode of the Invention]

First, a method for homogenizing the energy distribution of the beam spot with the use of the optical waveguide is explained in reference to FIGS. 1. Initially, a plane view of FIG. 1(a) is explained. An optical waveguide 102 having a pair of reflection planes 102a and 102b provided oppositely, and a surface to be irradiated 103 are

prepared, and light beams are made to be incident from the left side on paper. When there is the optical waveguide 102, the light beam is drawn with a continuous line 101a. When there is not the optical waveguide 102, the light beams are drawn with dotted lines 101b. When there is not the optical waveguide 102, the light beams being incident from the left side on paper reach regions 103a, 103b and 103c in a surface to be irradiated as indicated with dotted lines 101b.

[0043]

On the other hand, when there is the optical waveguide 102, as indicated with the light beam 101a, the light beams are reflected by the reflection planes of the optical waveguide 102 and all the light beams reach the region 103b in the surface to be irradiated. In other words, all the light beams that reach the regions 103a and 103c in the case where the optical waveguide 102 is not provided reach the region 103b in the surface to be irradiated in the case where the optical waveguide 102 is provided. Thus, when the light beams are made to be incident into the optical waveguide 102, the light beams are reflected repeatedly in the optical waveguide and are led to the exit. That is to say, the light beams are overlapped on the region 103b in the surface to be irradiated, which is the same position as if the incident laser beams are folded. In this example, the length of the total divergence of the laser beams 103a, 103b, and 103c on the surface to be irradiated 103 when there is not the optical waveguide is defined as A, and the length of the laser beam divergence 103b on the surface to be irradiated 103 when there is the optical waveguide is defined as B. Then, A/B corresponds to the number of laser beams divided by the homogenizer described in the related art. Thus, when the incident laser beam is divided and all the divided light beams are overlapped on the same position, the energy distribution of a light beam is homogenized on the overlapped

position.

[0044]

Usually, the more the homogenizer divides the light beam, the more homogeneous the energy distribution becomes on the position where the divided light beams are overlapped. The number of the light beams divided by the optical waveguide 102 can be increased when the light beams are reflected more times in the optical waveguide 102. In other words, the length of a pair of reflection planes of the optical waveguide in the direction to which the light beams are incident may be made longer. In addition, the number of divided light beams can be increased by narrowing the space between the reflection planes provided oppositely, or by enhancing NA (numerical aperture) of the light beam being incident.

[0045]

The optical system for forming a rectangular beam spot including a beam homogenizer disclosed in the present invention is explained with reference to FIGS. 2. In a plane view of FIG. 2 (a), the direction perpendicular to the paper is the direction of the minor axis of the rectangular beam spot. Hereinafter, a light pipe can be used as the optical waveguide.

[0046]

First, the plane view of FIG. 2 (a) is explained. A laser beam emitted from a laser oscillator 201 is propagated in the direction indicated by an arrow in FIGS. 2 and then the laser beam is incident into a cylindrical lens 202. The laser beam is focused through the cylindrical lens 202 in the direction of the major axis of the rectangular beam spot and then is incident into an optical waveguide 203 having a pair of reflection planes 203a and 203b provided oppositely. The laser beam being incident into the

optical waveguide 203 is reflected repeatedly in the optical waveguide 203 and is led to the exit. A plane having homogeneous energy distribution in the direction of the major axis of the rectangular beam spot is formed at the exit of the optical waveguide 203. For example, the optical waveguide 203 may have a length of 300 mm in the direction to which the light beam is incident, and a distance of 2 mm between the reflection planes.

[0047]

The longer the length of the optical waveguide 203 in the direction to which the laser beam is incident is, or the shorter the focal length of the cylindrical lens 202 is, the more homogeneous the energy distribution becomes. However, the actual system must be manufactured in consideration of the size of the optical system, and thereby the length of the optical waveguide and the focal length of the cylindrical lens must be practical in accordance with the size of the system.

[0048]

A cylindrical lens 204 projects a plane of the rectangular beam spot formed at the exit of the optical waveguide 203, which has homogeneous energy distribution in the direction of the major axis of the rectangular beam spot, to a surface to be irradiated 208. In other words, the plane having homogeneous energy distribution and the surface to be irradiated 208 are conjugated with respect to the cylindrical lens 204. This homogenizes the energy distribution of the rectangular beam spot in the direction of its major axis and determines the length thereof in the direction of its major axis.

[0049]

The present invention having the optical waveguide 203 can remedy the structural problem and the problem of the manufacturing accuracy of the cylindrical lens array,

and the problem of the manufacturing accuracy of the cylindrical lens for converging the divided light beams, which cause the inhomogeneity of the energy distribution of the rectangular beam spot on the surface to be irradiated in the conventional optical system.

[0050]

Next, a side view of FIG. 2 (b) is explained. The laser beam emitted from the laser oscillator 201 is divided through cylindrical lens arrays 205a and 205b in the direction of the minor axis of the rectangular beam spot. The laser beams divided by the cylindrical lens arrays 205a and 205b are overlapped on the same surface by a cylindrical lens 206 to homogenize the energy distribution of the rectangular beam spot in the direction of its minor axis.

[0051]

A plane of the rectangular beam spot formed by the cylindrical lens 206, which has homogeneous energy distribution in the direction of the minor axis of the rectangular beam spot, is projected to the surface to be irradiated 208 through a doublet cylindrical lens consisting of cylindrical lenses 207a and 207b. Thus, the energy distribution of the rectangular beam spot is homogenized in the direction of its minor axis on the surface to be irradiated 208, and the length thereof in the direction of its minor axis is determined. The doublet cylindrical lens does not need to be employed, but when the doublet cylindrical lens is employed, spatial margin can be given because a certain degree of distance can be secured between the optical system and the irradiation surface. It is to be noted that when the homogeneity of the beam spot on the surface to be irradiated is not required too much, or when F-number of the doublet cylindrical lens is extremely high, a singlet cylindrical lens may be employed.

[0052]

With the optical system having the above structure, it is possible to form the rectangular beam spot having homogeneous energy distribution in the directions of its major axis and its minor axis on the surface to be irradiated.

[0053]

The laser oscillator which is to be combined with the optical system for forming the rectangular beam spot and which includes the beam homogenizer disclosed in the present invention preferably has high output and the wavelengths that can be sufficiently absorbed in the semiconductor film. When a silicon film is employed as the semiconductor film, the wavelength of the laser beam emitted from the laser oscillator is preferably not longer than 600 nm in consideration of the absorption ratio. For example, there are an excimer laser, a YAG laser (harmonic), and a glass laser (harmonic) given as the laser oscillator to emit such a laser beam.

[0054]

In addition, although high output is not obtained yet by the current technique, there are a YVO_4 laser (harmonic), a YLF laser (harmonic), and an Ar laser given as the laser oscillator to emit a laser beam of appropriate wavelength for crystallizing the silicon film.

[0055]

Hereinafter, a method for manufacturing a semiconductor device of the present invention by using the beam homogenizer and the laser irradiation apparatus of the present invention is explained. First, a substrate having a size of 600 mm × 720 mm × 0.7 mm is prepared as the substrate, for example. A no-alkali glass substrate having enough resistance against a temperature up to 600°C such as aluminoborosilicate glass, bariumborosilicate glass or aluminosilicate glass can be used as this substrate. A

silicon oxide film is formed to a thickness of 200 nm over the glass substrate as a base film. Moreover, an amorphous silicon film is formed thereover to a thickness of 55 nm. These films are formed by a sputtering method. They may be formed by a plasma-CVD method alternatively.

[0056]

The substrate with the films formed thereon is put in an atmosphere of nitrogen at a temperature ranging from 450 to 500°C for 1 to 3 hours. This process is to reduce hydrogen concentration in the amorphous silicon film. This process is performed since the film cannot resist against the laser energy when the amorphous silicon film contains too much hydrogen. The hydrogen concentration in the amorphous silicon film is appropriate on the order of $10^{20}/cm^3$. Here, $10^{20}/cm^3$ means that 10^{20} hydrogen atoms exist in 1 cm^3.

[0057]

For example, in this embodiment mode, a XeCl excimer laser is used as the laser oscillator. In this embodiment, the XeCl excimer laser (wavelength 308 nm, pulse width 30 ns) STEEL 1000 manufactured by Lambda Physik, Inc. is employed. The excimer laser is a pulsed laser. The excimer laser has a maximum energy of 1000 mJ per a pulse, an oscillation wavelength of 308 nm, and a maximum frequency of 300 Hz. When the energy of the pulsed laser fluctuates within ±10%, preferably within ±5%, in every pulse during a laser treatment to one substrate, homogeneous crystallization can be performed.

[0058]

The fluctuation of the laser energy described above is defined as follows. In other words, the average value of the laser energy in the period of the irradiation to one

substrate is assumed to be standard. Then, the difference between the average value and the minimum value or the maximum value in the period of the irradiation is converted to percentage.

[0059]

Irradiation with the laser beam is performed, for example, while scanning the stage with the surface to be irradiated 208 shown in FIGS. 2 mounted thereon in the direction of the minor axis of the rectangular beam spot. On this occasion, a practitioner may decide the energy density and the scanning speed of the beam spot on the surface to be irradiated appropriately. The energy density may be appropriate in the range of 200 mJ/cm^2 to 1000 mJ/cm^2. It is feasible to perform laser annealing homogeneously when the scanning speed is selected in the range where the width of the rectangular beam spot in the direction of its minor axis is overlapped one another by about 90% or more. The optimum scanning speed depends upon the frequency of the laser oscillator, and it may be regarded to be proportional to the frequency thereof.

[0060]

In this way, the laser annealing process is completed. When such an operation is performed repeatedly, many substrates can be processed. In addition, when a substrate holder capable of storing a plurality of substrates and a transferring apparatus for transferring the plurality of substrates automatically between the substrate holder and the stage are prepared, substrates can be processed more effectively. For example, an active matrix liquid crystal display can be manufactured using the substrate according to a known method.

[0061]

The excimer laser is used as the laser oscillator in the above example. The

excimer laser is appropriate for the optical system in the above example because it has an extremely short coherent length of several μm. Some of the lasers shown below have a long coherent length. In the case of using such a laser, when the divided beams are combined in such a way that they have an optical path difference before being combined, it is possible to suppress the generation of the interference. Alternatively, the coherent length may be changed intentionally by making the laser beam transmit through an optical fiber or the like before the laser beam is incident into the optical system and then the laser beam may be incident into the homogenizer. It is also preferable to employ a harmonic of the YAG laser or a harmonic of the glass laser because high output can be obtained similarly and energy of the laser beam is sufficiently absorbed in the silicon film. There are a YVO_4 laser (harmonic), a YLF laser (harmonic), and an Ar laser given as the other appropriate laser oscillator for crystallizing the silicon film. These laser beams have wavelengths sufficiently absorbed in the silicon film.

[0062]

Although the above example uses the amorphous silicon film as the non-single crystalline semiconductor film, it is easily supposed that the present invention can be applied to other non-single crystalline semiconductors. For example, a compound semiconductor film having an amorphous structure, such as an amorphous silicon germanium film, may be used as the non-single crystalline semiconductor film. A poly-crystalline silicon film may be used as the non-single crystalline semiconductor film alternatively.

[0063]

[Embodiment]

[Embodiment 1]

FIGS. 3 show an example of the optical system including an optical waveguide to be explained in this embodiment. A light pipe can be used as the optical waveguide. First, a plane view of FIG. 3 (a) is explained. A laser beam emitted from a laser oscillator 301 is propagated in the direction indicated by an arrow in FIGS. 3. In the plane view of FIG. 3 (a), the direction perpendicular to the paper is the direction of the minor axis of the rectangular beam spot.

[0064]

Initially, the laser beam is expanded by spherical lenses 302a and 302b. When the laser oscillator 301 emits a sufficiently large beam spot, such a structure is not necessary. It is to be noted that the optical system for expanding the shape of the beam spot, such as the spherical lenses 302a and 302b, is generally referred to as a beam expander.

[0065]

The laser beam expanded by the beam expander is focused in the direction of the major axis of the rectangular beam spot through a cylindrical lens 303 having a thickness of 20 mm with the first surface having a radius of curvature of 194.25 mm and the second surface being plane. The sign of the radius of curvature is positive when the center of the curvature is on the side where the light beam is emitted with respect to the lens surface. The sign is negative when the center of the curvature is on the side where the light beam is incident with respect to the lens surface. In addition, it is to be noted that a lens surface where the laser beam is incident is defined as the first surface, and a lens surface where the laser beam is emitted is defined as the second surface.

[0066]

An optical waveguide 304 including a pair of reflection planes 304a and 304b provided oppositely is arranged in such a way that the entrance of the optical waveguide 304 is positioned in the focal point of the cylindrical lens 303. The laser beam being incident into the optical waveguide 304 is reflected repeatedly in the optical waveguide 304 so as to homogenize the energy distribution thereof and then led to the exit. A plane having homogeneous energy distribution in the direction of the major axis of the rectangular beam spot is formed at the exit of the optical waveguide 304. The optical waveguide 304 has a length of 200 mm in the direction in which the laser beam travels, and a distance of 2 mm between the reflection planes.

[0067]

A cylindrical lens 305 has a thickness of 5 mm with the first surface having a radius of curvature of 9.7 mm and the second surface being plane, which is positioned 20 mm behind the exit of the optical waveguide 304. A plane of the rectangular beam spot formed at the exit of the optical waveguide 304, which has homogeneous energy distribution in the direction of the major axis of the rectangular beam spot is projected by the cylindrical lens 305, to an irradiated surface 309 positioned 3600 mm behind the cylindrical lens 305. In other words, the plane having homogeneous energy distribution in the direction of the major axis and the surface to be irradiated 309 are conjugated with respect to the cylindrical lens 305. This homogenizes the energy distribution of the rectangular beam spot in the direction of its major axis and determines the length thereof in the direction of its major axis. In this embodiment, the cylindrical lens 305 is employed as the lens for projecting the laser beam emitted from the optical waveguide 304 on the surface to be irradiated 309. In order to reduce aberration more, however, a doublet cylindrical lens may be used. The doublet

cylindrical lens is a set of lenses consisting of two cylindrical lenses. A set of lenses consisting of three or more lenses may be used alternatively. The number of lenses may be determined in accordance with the designed system or required specification.

[0068]

Next, a side view of FIG. 3 (b) is explained. The laser beam emitted from the laser oscillator 301 is expanded through the beam expander including the spherical lenses 302a and 302b. The laser beam expanded through the beam expander is focused in the direction of the minor axis of the rectangular beam spot through a cylindrical lens 306 having a thickness of 20 mm with the first surface having a radius of curvature of 486 mm and the second surface being plane, which is positioned 773.2 mm behind the cylindrical lens 305.

[0069]

An optical waveguide 307 having a pair of reflection planes 307a and 307b provided oppositely is arranged in such a way that the entrance of the optical waveguide 307 is positioned in the focal point of the cylindrical lens 306. The laser beam being incident into the optical waveguide 307 is reflected repeatedly in the optical waveguide 307 so as to homogenize the energy distribution thereof and then led to the exit. A plane having homogeneous energy distribution in the direction of the minor axis of the rectangular beam spot is formed at the exit of the optical waveguide 307. The optical waveguide 307 has a length of 250 mm in the direction in which the laser beam travels, and a distance of 2 mm between the reflection planes.

[0070]

A doublet cylindrical lens 308a and 308b arranged in the position 1250 mm behind the exit of the optical waveguide 307 projects the plane of the rectangular beam

spot formed at the exit of the optical waveguide 304, which has homogeneous energy distribution in the direction of the minor axis of the rectangular beam spot on the surface to be irradiated 309 positioned 237 mm behind the doublet cylindrical lens.

[0071]

One cylindrical lens constituting the doublet cylindrical lens has the first surface having a radius of curvature of 125 mm and the second surface having a radius of curvature of 77 mm, and has a thickness of 10 mm. The other cylindrical lens has the first surface having a radius of curvature of 97 mm and the second surface having a radius of curvature of -200 mm, and has a thickness of 20 mm. The two cylindrical lenses are arranged to have a distance of 5.5 mm in between. Thus, the energy distribution of the rectangular beam spot is homogenized in the direction of its minor axis and determines the length thereof in the direction of its minor axis is determined. An irradiation surface may be arranged just after the optical waveguide 307 without using the doublet cylindrical lens, but when the doublet cylindrical lens is employed, spatial margin can be given because a certain degree of distance can be secured between the optical system and the irradiation surface.

[0072]

The optical system including the optical waveguide shown in FIGS. 3 can form a rectangular beam spot having a size of 300 mm in the direction of the major axis and 0.4 mm in the direction of the minor axis, and having homogeneous energy distribution. FIGS. 4 show the simulation result by optical design software. FIG. 4 (a) is a chart showing the energy distribution of the beam spot formed on the plane having a size of ±0.3 mm in the direction of the minor axis and ±200 mm in the direction of the major axis from the center of the rectangular beam spot. FIGS. 4 (b) and (c) are

cross-sectional views of energy distribution along a line A and a line B in FIG. 4 (a) respectively. A vertical axis shows the laser intensity (A.U.), and a horizontal axis shows the length (mm).

[0073]

The laser annealing is performed to the semiconductor film with the optical system including the optical waveguide shown in this embodiment with the method according to the embodiment mode, for example. The semiconductor film can be used to manufacture an active matrix liquid crystal display, for example. A practitioner may manufacture this device according to a known method.

[0074]

[Embodiment 2]

This embodiment shows an example of an optical system different from that described in the embodiment mode. FIGS. 5 show the example of the optical system to be explained in this embodiment. In addition, a light pipe can be used as the optical waveguide.

[0075]

In FIGS. 5, the laser beam goes through the same optical path as that shown in FIGS. 3 except the optical waveguides 504 and 507. Each of the optical waveguides 504 and 507 has a pair of reflection planes provided oppositely similarly to the optical waveguide 304. The optical waveguide 304 has a hollow space between the pair of reflection planes. On the other hand, the optical waveguides 504 and 507 each have a space between the pair of reflection planes provided oppositely, which is filled with the medium having a refractive index of n (>1). This is the different point between these optical waveguides. When the light beams are incident into the optical waveguides

504 and 507 at a critical angle or more, the light beams are totally reflected on the reflection plane according to the same principle as the optical fiber. For example, when the optical waveguide made of quartz (refractive index is approximately 1.5) is arranged in the air, it is possible to obtain the optical waveguide having total reflection planes in the interface between the air and the optical waveguide. With the optical waveguide described above employed, the transmittance of the laser beam is considerably higher compared to the case where the laser beam is not totally reflected. Thus, the laser beam emitted from the laser oscillator 501 can be propagated to the irradiation surface 509 more effectively.

[0076]

In addition, an optical waveguide with a multilayer structure may be used instead of the optical waveguides 504 and 507 in FIGS. 5. Typically, an optical waveguide made of two materials shown in FIG. 7 (A), in which an inner material 702 (quartz containing germanium, for example) has a higher refractive index than an outer material 701 (quartz, for example) can be used.

[0077]

FIG. 7 (B) is a cross-sectional view taken along a line (A)-(A') in the optical waveguide shown in FIG. 7 (A). In addition, FIG. 7 (C) is an enlarged view of the reflection plane in FIG. 7 (B). When the light beams 703 are incident into the optical waveguide at an incidence angle θ not less than the critical angle θ_0, the incident laser beam are totally reflected between the reflection planes provided oppositely.

[0078]

In addition, the entrance surfaces of the optical waveguides 504 and 507 may be timely coated in order to reduce the reflectivity of the laser beam at the entrance

surface of the optical waveguide when the laser beam is incident into the optical waveguides 504 and 507.

[0079]

The optical system shown in FIGS. 5 can form a rectangular beam spot having a size of 300 mm in the direction of its major axis and 0.4 mm in the direction of its minor axis and homogeneous energy distribution.

[0080]

The laser annealing is performed to the semiconductor film using the optical system shown in this embodiment by the method according to the invention embodiment mode for example. The semiconductor film can be used to manufacture an active matrix liquid crystal display for example. A practitioner may manufacture the display according to a known method.

[0081]

[Effect of the Invention]

The present invention provides a laser irradiation apparatus comprising a beam homogenizer equipped with an optical waveguide. The optical waveguide comprises a pair of reflection planes provided oppositely and can homogenize the energy distribution of the rectangular beam spot in a direction of its major axis on the surface to be irradiated.

[0082]

When the beam homogenizer for forming a rectangular beam spot with the optical waveguide disclosed in the present invention is used, it becomes possible to form the rectangular beam spot having homogeneous energy distribution in a direction of its major axis on the surface to be irradiated without using the optical lens that

requires to be manufactured with high accuracy. In addition, the optical waveguide is more preferable since it acts upon the rectangular beam spot in a direction of its minor axis and can also homogenize the energy distribution in the direction thereof on the surface to be irradiated. When the rectangular beam spot emitted from the laser irradiation apparatus with the use of this beam homogenizer is scanned on the semiconductor film in a direction of its minor axis, the inhomogeneous crystallinity due to the inhomogeneity of the energy distribution of the beam spot can be suppressed, and the homogeneity of the crystallinity in the surface of the substrate can be enhanced. In addition, when the present invention is applied to a mass-production line of a low-temperature polysilicon TFTs, it is possible to efficiently manufacture a TFT having an excellent operating characteristic.

[Brief Description of the Drawings]

[FIGS. 1] Drawings to explain homogenization of the energy distribution of the beam spot by an optical waveguide.

[FIGS. 2] Drawings showing an example of a beam homogenizer with the use of an optical waveguide disclosed in the present invention.

[FIGS. 3] Drawings showing an example of a beam homogenizer with the use of an optical waveguide disclosed in the present invention.

[FIGS. 4] The energy distribution of the rectangular beam spot obtained by the beam homogenizer shown in FIGS. 3.

[FIGS. 5] Drawings showing an example of a beam homogenizer with the use of an optical waveguide disclosed in the present invention.

[FIGS. 6] Drawings showing the conventional beam homogenizer.

[FIGS. 7] Drawings showing an example of an optical waveguide disclosed in

the present invention.

[Document Name] Abstract

[Abstract]

[Problem]

The present invention provides a beam homogenizer capable of forming a rectangular beam spot having homogeneous energy distribution in a direction of its major axis without using the optical lens required to be manufactured with high accuracy. In addition, the present invention provides a laser irradiation apparatus capable of delivering the laser beam having homogeneous energy distribution in a direction of its major axis. Furthermore, the present invention provides a method for manufacturing a semiconductor device which can enhance crystallinity in the surface of the substrate and can manufacture a TFT with a high operating characteristic.

[Solving Means]

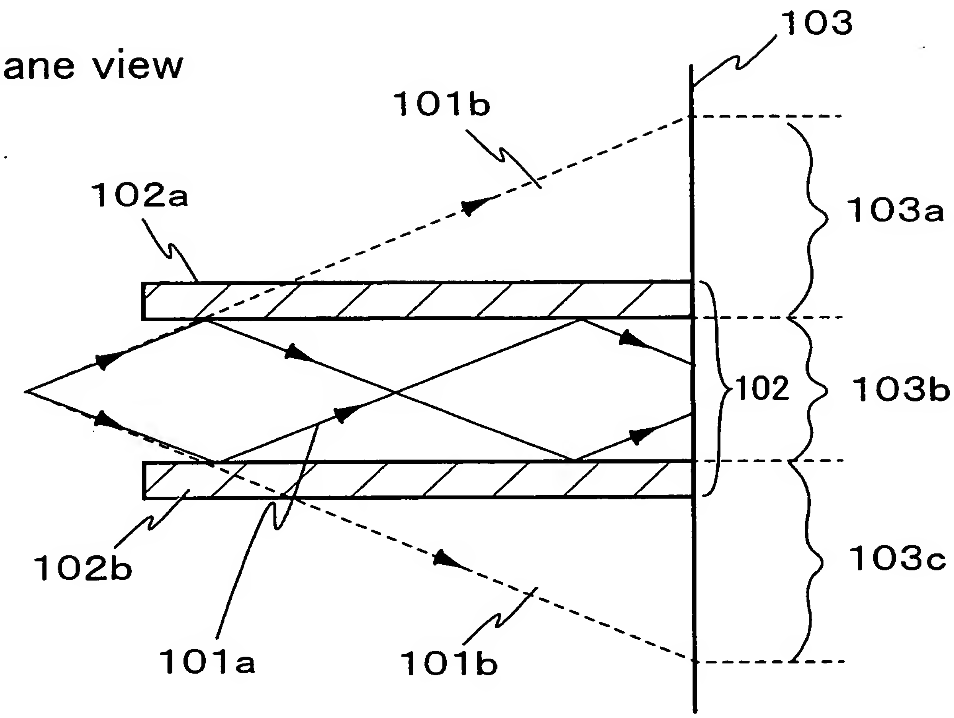
The beam homogenizer, one of the present invention, is to shape the beam spot on the surface to be irradiated into a rectangular spot having an aspect ratio of 10 or more, preferably 100 or more, and comprises an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in the direction of its major axis.

[Selected Drawing] FIGS.2

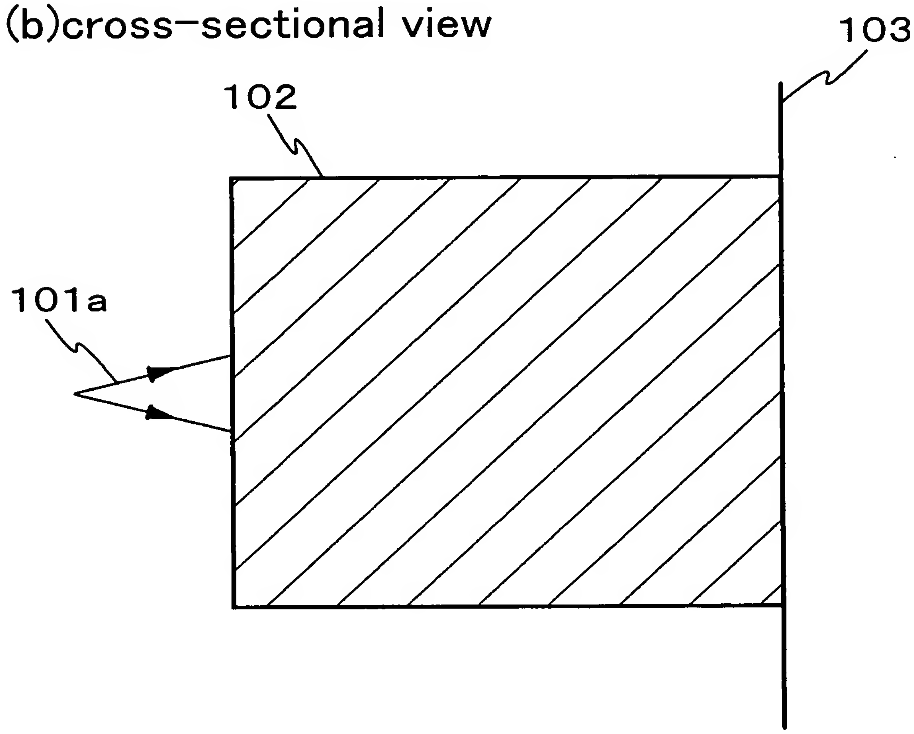
[Name of Document] Drawing

【Fig.1】

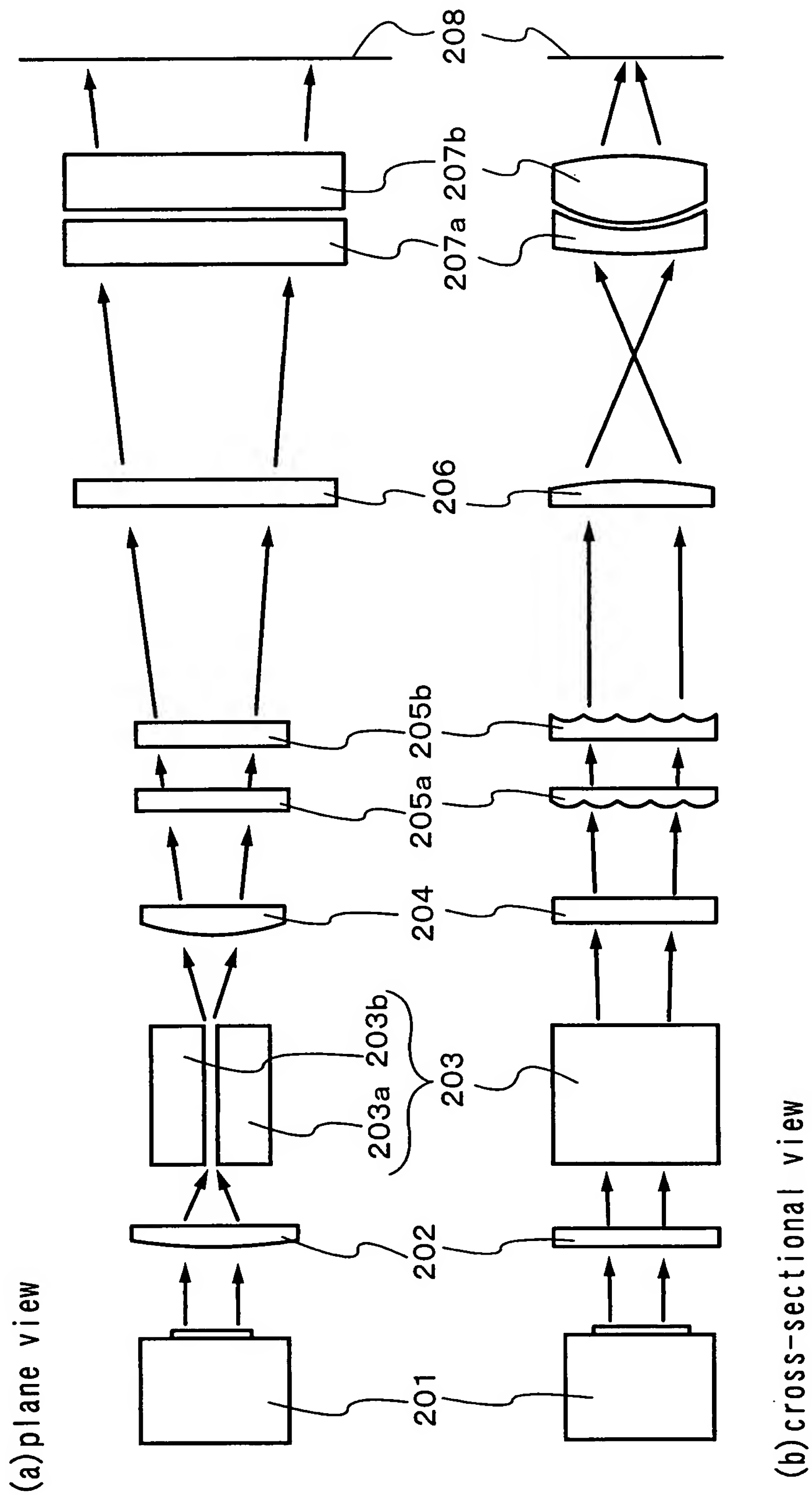
(a)plane view



(b)cross-sectional view

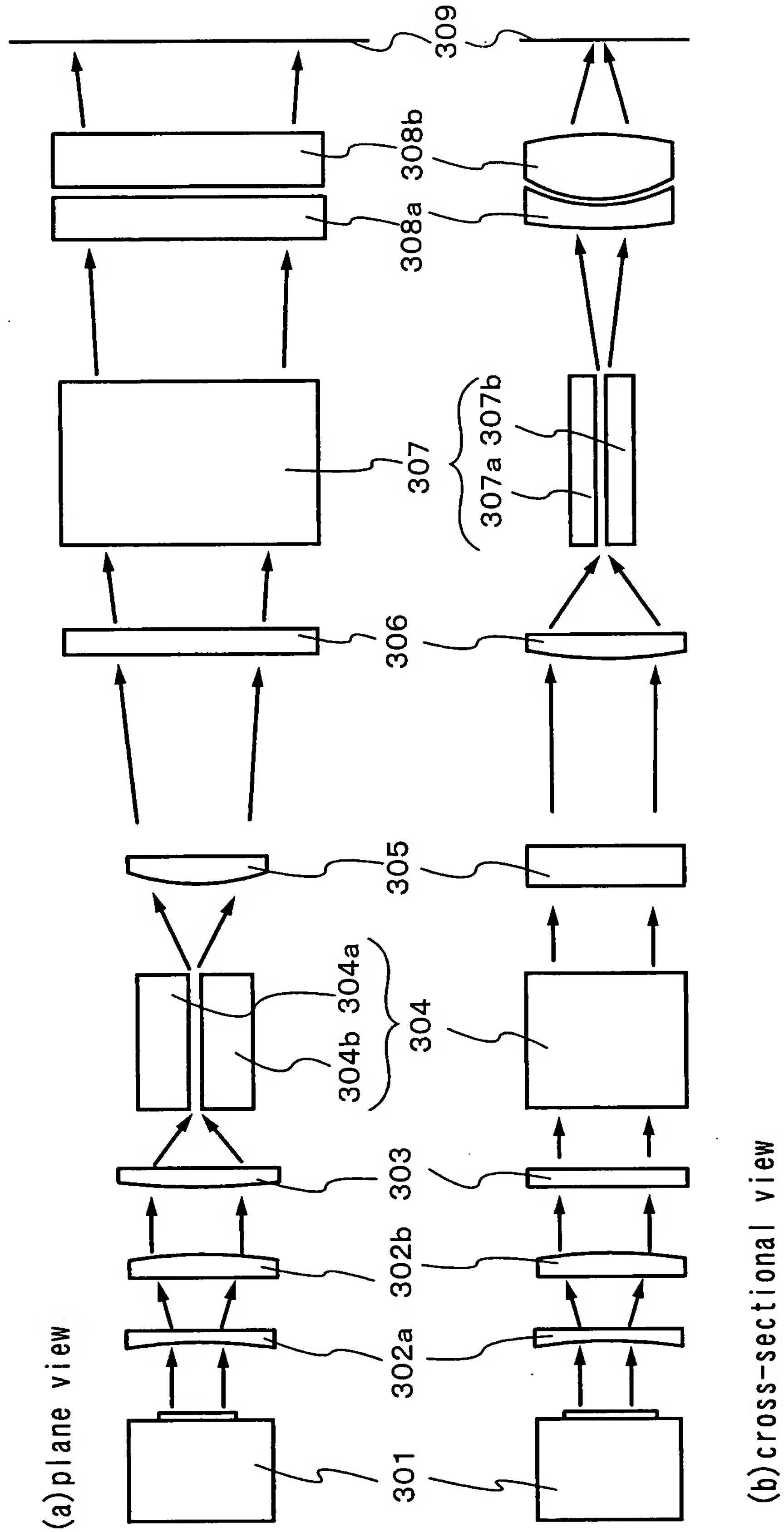


【Fig.2】



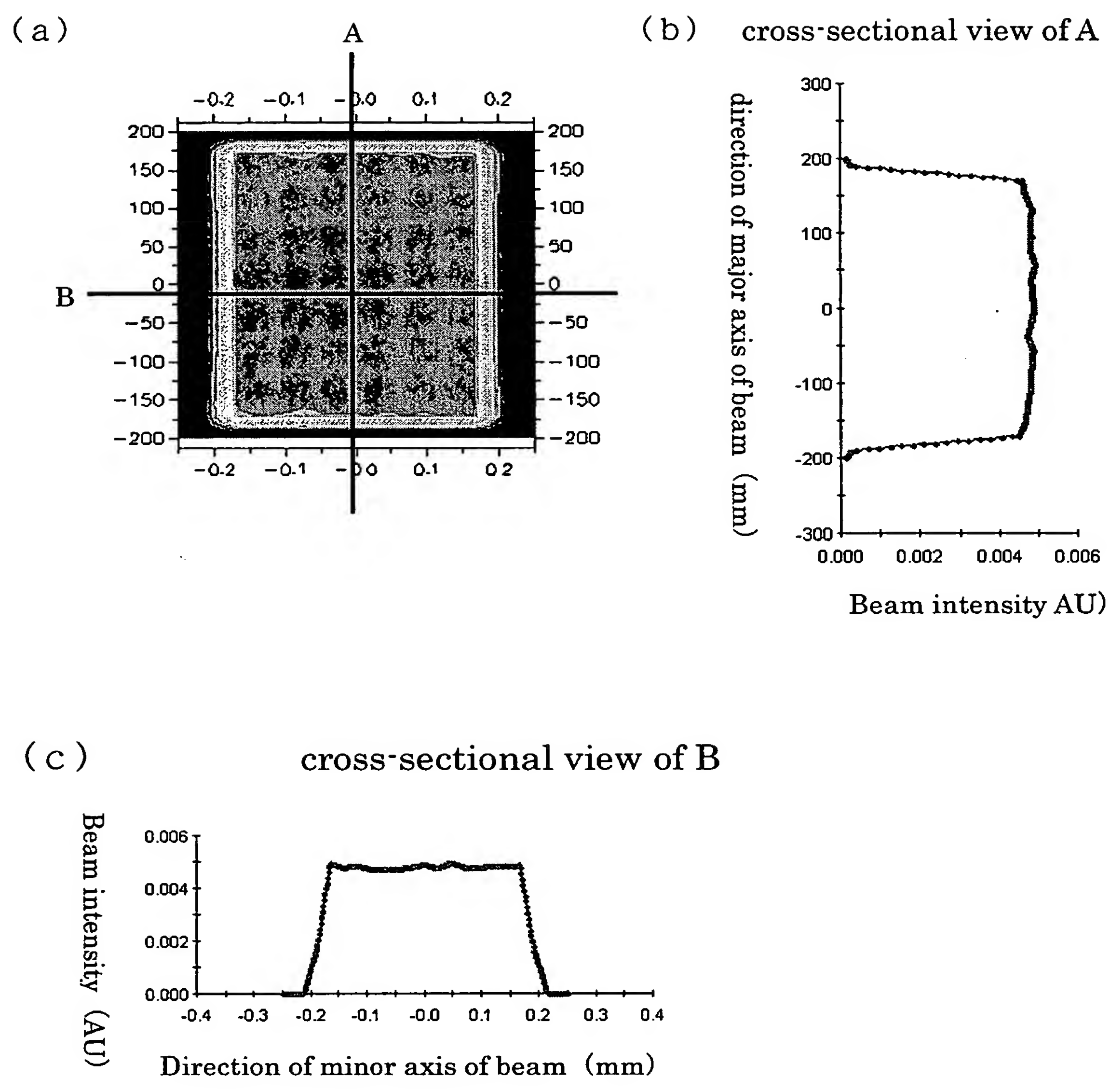
(a)plane view
(b)cross-sectional view
201
202
203
203a
203b
204
205a
205b
206
207a
207b
208

【Fig.3】



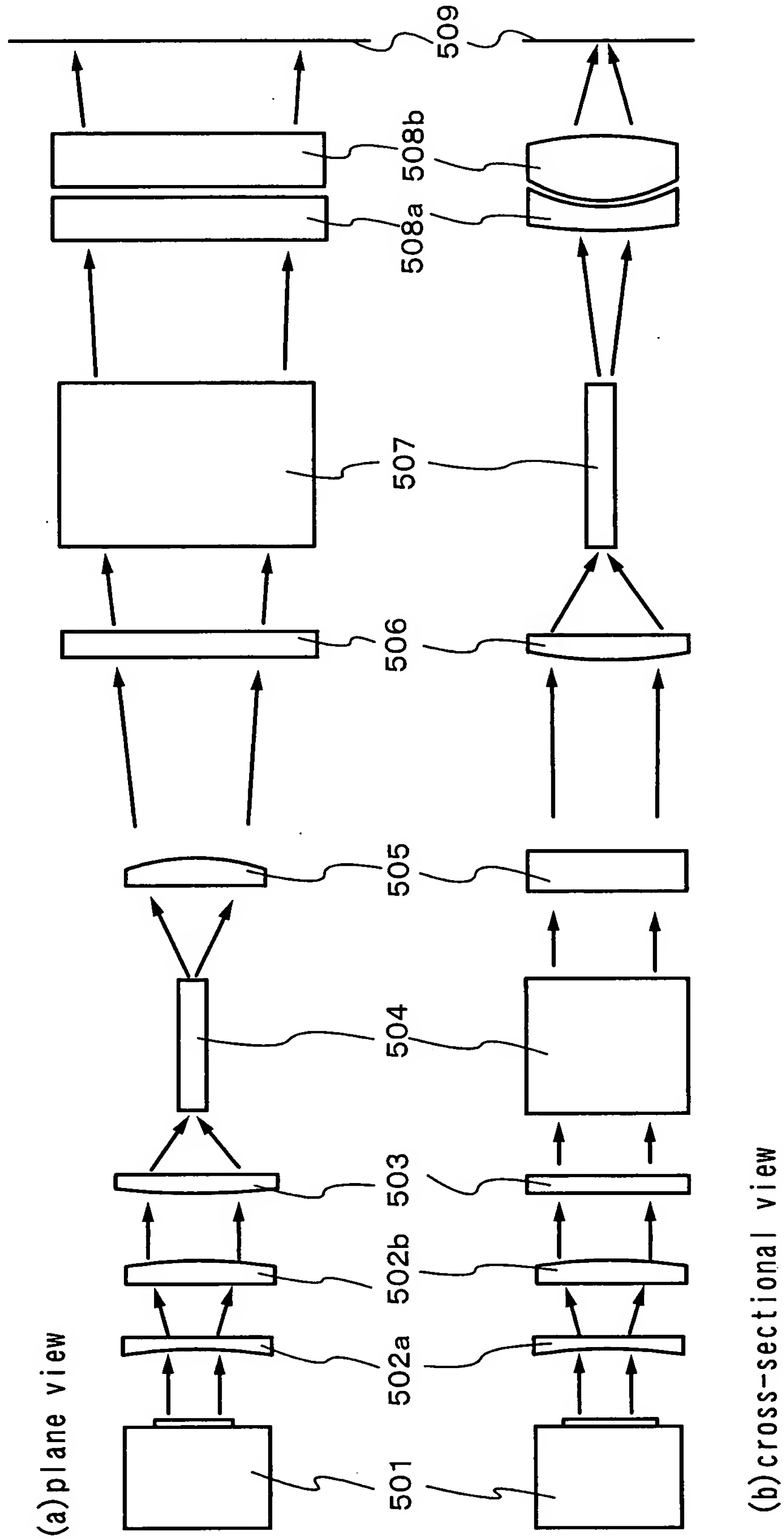
(a)plane view
(b)cross-sectional view
301
302a
302b
303
304
304a
304b
305
306
307
307a
307b
308a
308b
309

【Fig. 4】



(a)
A
B
-0.2
-0.1
0.0
0.1
0.2
200
150
100
50
0
-50
-100
-150
-200
(b) cross-sectional view of A
direction of major axis of beam (mm)
300
200
100
0
-100
-200
-300
0.000
0.002
0.004
0.006
Beam intensity AU)
(c) cross-sectional view of B
Beam intensity (AU)
0.006
0.004
0.002
0.000
-0.4
-0.3
-0.2
-0.1
-0.0
0.1
0.2
0.3
0.4
Direction of minor axis of beam (mm)

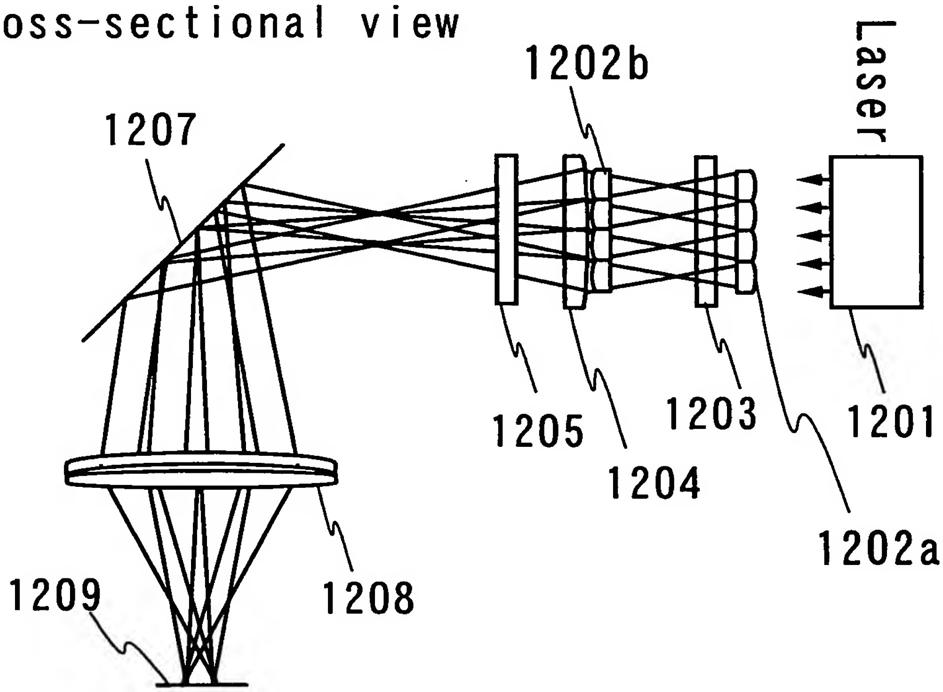
【Fig.5】



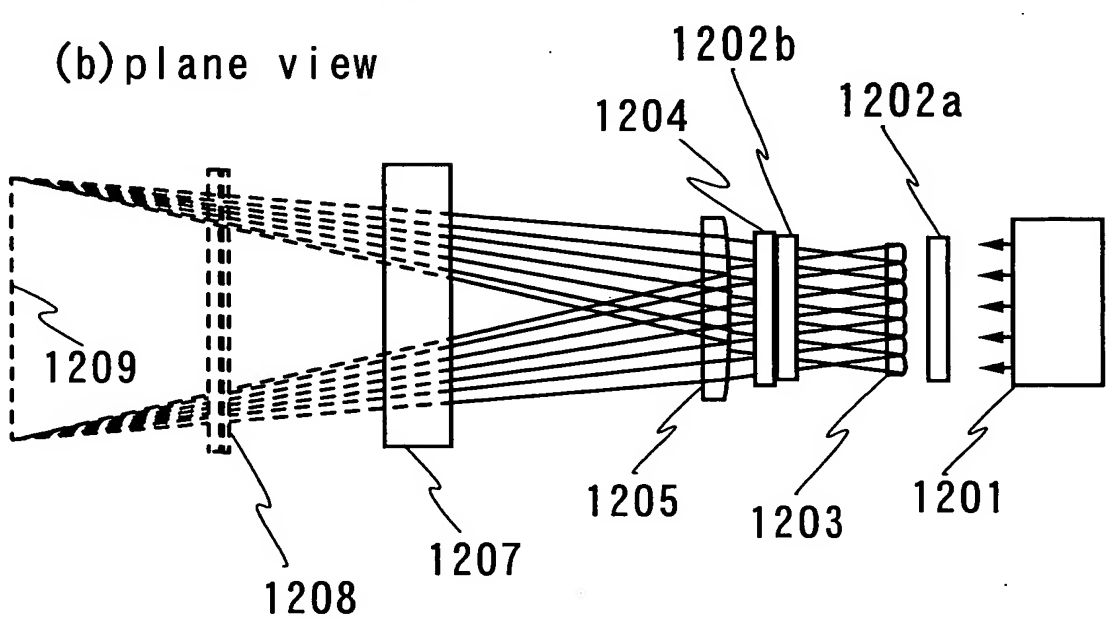
509
508b
508a
507
506
505
504
503
502b
502a
501
(a)plane view
(b)cross-sectional view

【Fig. 6】

(a)cross-sectional view

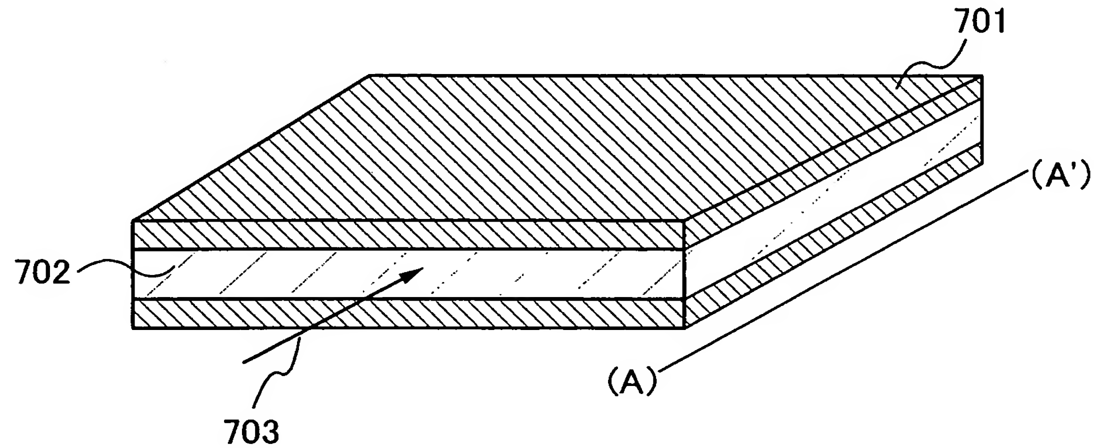


(b)plane view

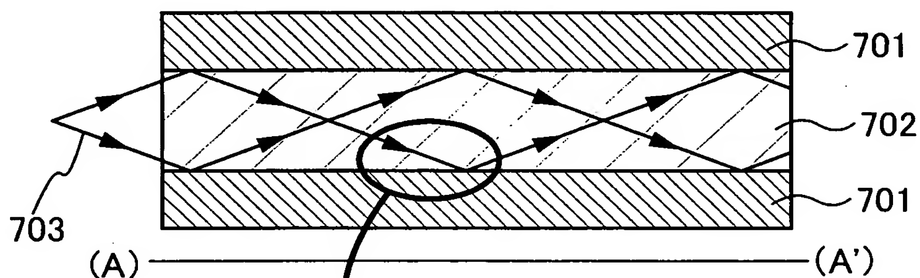


【Fig.7】

(A)



(B)



(C)